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The Impact of Urban Structure Changes on the Airflow Speed Circulation in Historic Karbala, Iraq

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Abstract

This study investigates a dynamic air flow circulation in the urban historic structures of Karbala, which is one of the typical examples of historic nuclei in Iraq as well as the Middle Eastern region. The mechanism of natural urban ventilation system of the city is continuously facing forces of change for different reasons, such as socioeconomic, political, and environmental. These changes in the city form included but not limited to: large parts of urban historic structures have been removed and new concrete structures and modern streets, that have different geometry, dimensions, and materials, have been added. Such changes affect ~~a~~ the pattern of street networks and the mass-void proportions in the old urban structures, which were built in efficiency providing ventilation and cooling naturally, and could have great impact on the speed and behavior of the air flow circulation. For the analysis purposes, two phases which are remarkable in forming the old structure of Karbala have been selected and digitized. These phases include the organic urban structures before the initial acts of road building in the beginning of the previous century, before British mandate in 1920, as well as the new comprehensive master plan that was carried out for the city during 1990s, after the end of the Gulf War II. The study area was strictly defined to represent traditional environment relied on using natural ventilation system. Four simulation models of the study area have been created for the aforementioned phases. The first set has shown the air flow speed, while the second set has presented LMA, i.e. the local mean age. The simulation process was supported by surveyed and historic meteorological data. Results show that the changes of old urban structures affect the air flow circulation speed significantly, but more importantly, these results offer a useful source for contemporary urban planning, using comprehensive plans, in historic nuclei with similar characteristics to Karbala in both local and regional areas. One significant limitation of this study, however, is that it has not involved single urban blocks or residential units in the analysis.

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Keywords: Airflow, Urban Structure, Natural Ventilation System, Karbala

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1. Introduction

Built with a high sense of using traditional architecture solutions and organic growth, historic Karbala is one of the remaining examples of the old urban structures in Iraq and the Middle Eastern region. Located about 100km (62 miles) southwest of Baghdad, Figure (1), its old structure is primarily characterized by two central monumental shrines, zigzag street networks, and urban compact units containing open areas are called courtyards. Across long span of its evolution, more than 1000 years, the old urban structure is continuously facing forces of change. In particular, a hugely change of the city form can be noted between two phases. In a very beginning of the last century, the city form was compact and relatively small. Then, the city expanded enormously and its old structure was complemented by massive new urban developments since 1990s till now. Large parts of the old structures have been cleared away and new concrete structures, which have different geometric, constructional, and environmental characteristics, have been added [1], as shown in Figure (2). The pattern of old street networks and the compact residential clusters were built and developed to accommodate the prevailing continental climate conditions such as high temperature and frequent dust storms [2]. Such a compact and high density urban development has been compensated by a natural ventilation system (NVS) to achieve an effective airflow circulation for both indoor and outdoor environments [3]. This NVS has worked based on two sets of components: the first set is existed inside the compact residential units including *Badgirs* (wind catchers), courtyards, and *sirdabs* (basements). The second set is formed by the network of zigzag streets that cause continuous changes in the air flow speed and direction [4]. To illustrate performance of NVS, this study aims to address this question: what could be the effects of altering the old urban structures on the airflow speed circulation of the NVS? Mechanism of the NVS is essentially working based on the movement of the airflow, which is going to be analyzed through simulation models of the urban structures in both cases of before and after introducing the changes. The study is organized in six sections including: a main background of the study, mechanism of the NVS, relevant works, methodology, results and discussion, and finally conclusion.

Fig 1: a-the location of Karbala, Iraq; b-the selected site of the study area. Source: (Attia, 2009).

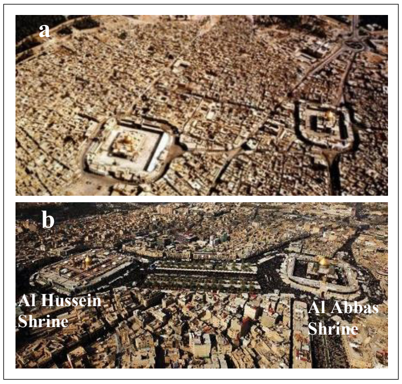

Fig 2: a- the old site; b-the new site (after changes). Source: (Attia, 2009)

2. Mechanism of the Natural Ventilation System

Mechanism of natural ventilation system relies on the efficiency of airflow circulation between street networks and a set of architectural components inside urban clusters Figure (3). Basically, air streams flow from street networks into *badgirs* that are placed above roof surfaces of compact units in relation with their parapets. They often have faced northwest air streams, prevailing winds, to gain maximum benefits of cool breezes during summer months. Then, cool breezes move from the urban clusters through *badgirs'* shafts to the basement floor, known locally *'sirdab'*, and finally move into the courtyard through narrow windows for ventilating and cooling purposes [3][5]. This mechanism has worked in traditional urban structures for many decades on the basis of convection process pushing cool streams outside environment into compact units in a cyclic manner. Because of aforementioned changes, the airflow speed and behavior could be also change and affect the efficiency of the NVS.

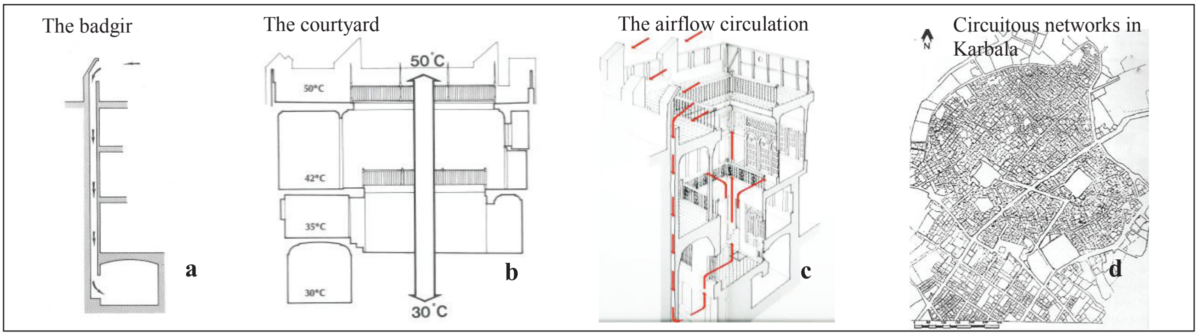

Fig 3: components of the NVS; a- *Badgir*; b- courtyard; c-the airflow circulation through a residential unit, and d-circuitous streets networks Sources: a, b, and c adopted from (Warren and Fethi, 1982); and d, (Attia, 2009).

3. Main Relevant Works

Studies have addressed the efficiency of the NVS in hot-arid regions divided into two sets. First, those that have focused on describing traditional architectural elements including courtyards, *badgirs*, and *sirdabs* those contribute to the operation of the NVS. The second set examines effects of the geometry of the built environment on the performance of airflows in the NVS. Of the first group, Al-Azzawi has conducted an analytic study to understand the roles of the aforementioned architectural elements on the pattern of urban life of Iraqi families [6]. Warren et al (1982) and Mortada (2013) have confirmed that solutions of traditional architecture in these regions were built based on a high sense of sustainability and pushing inhabitants to be relied on natural sources of energy to ventilate and cool their houses without using modern technologies [5] [7]. Shahine (2006) has outlined that understanding the role of these elements in interacting with orientation of prevailing winds can provide criteria used in designing sustainable contemporary housing [4]. Of the second group, Tablada et al (2009) have investigated the impacts of new housing interventions on the NVS using to cool, ventilate, and comfort for the majority of inhabitants in the Historical Centre of Havana. Findings have shown that cross ventilation between wide courtyards can provide higher indoor ventilation rates than a single narrow courtyard [8]. In addition, there are works, on the site's coverage considerations and the ability of buildings in terms of losing and gaining heat [2], on the impacts of exposed buildings' surfaces based on the surface-to-volume ratio that defines the size interaction with climatic conditions [9], on the urban density that shapes based on the ratio between height of urban clusters and streets' width [10], on the thermal performance of urban corridors in relation with their primarily orientation, and on the amount of shading on the canyons' surfaces[11][12]. Existing historic urban structures in hot-arid regions have mainly concerned of dramatic modifications whether adding new concrete structures, forming modern roads, or removing some parts. These changes are considered as obstacles to the mechanism of the airflow circulation in the NVS. There is still deficiency in investigating the airflow speed and behavior in the historic urban structures that are physically-structurally apt for changes.

4. Methods

The central zone of historic Karbala has been strictly selected as the study area that contains historic urban clusters and also most significant physical-structural changes. Two digitized maps of this zone have been generated from the historic maps of the city by using AutoCAD software program, as shown Figure (4). The two maps have been transformed from two dimensions into three dimensions by using Revit 3D CAD software. Before conducting the simulation processes, two stages should be completed here. First, all curved and zigzag edges of the building forms should be modifying into straight edges. Second, small adjacent urban blocks have merged together and formed a set of new big urban cluster. Field measurement of wind speeds was taken in the selected study area at different levels ranging between 2 to 120 meters (6.5 to 395 feet) in order to apply them on the four models by using FloVENT 9.3 application. Two simulated models have been used to examine the air flow speed and behavior for both the old and new urban structures while the other two models were used to estimate the local mean age of the air (LMA). The results of the analysis of the models before and after the changes were compared to define the differences of dynamic airflow circulations in the urban structures.

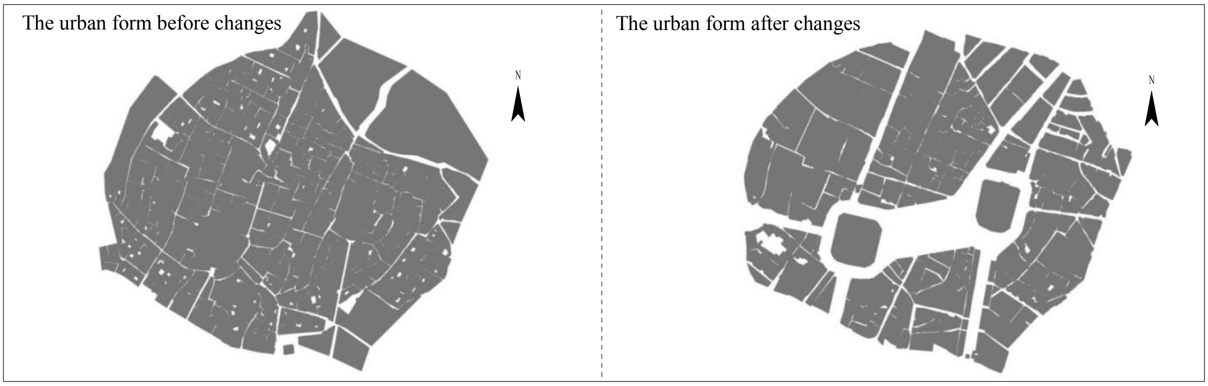

Fig 4: physical-structural changes of the former and current urban fabric forms of the historic Karbala.

5. Results and Discussion

Since the main purpose of this study is to investigate the wind speed behavior of the airflow circulation, the wind speed and the LMA were taken into account as the main two variables that used in the FloVENT application. The numerical coarse grid has been used to compare the accuracy of the results. Based on simulation results, the range scale of the wind speed was between 0 and 60 km/hr (37.3mil/hr) for the two models. The simulation results show that the first model has a wind speed ranges between 0 and 42 km/hr (26mil/hr) with maximum value of 55.7 km/hr (34.6mil/hr). For the second model, the wind speed ranges between 0 and 46.6 km/hr (28mil/hr) with maximum value of 56.7 km/hr (35.2mil/hr), see Figure (5). With respect to the LMA, the simulation results for the first model show that the air took 120 minutes in order to be changed, while in the second model the air took 116 minutes, as shown in Figure (6). These two figures show results of the wind speed and LMA for the two phases, before and after changes. It is thus obvious that the wind speed of the new urban structure has increased due to eliminating huge parts of the compact historic clusters. The increase of the previous values and the size of the exposed surfaces for solar radiations could influence the air pressures and temperature in the zigzag street networks. This can be considered as an obstacle preventing the air flow circulation from moving between the outside environment and inside compact urban clusters.

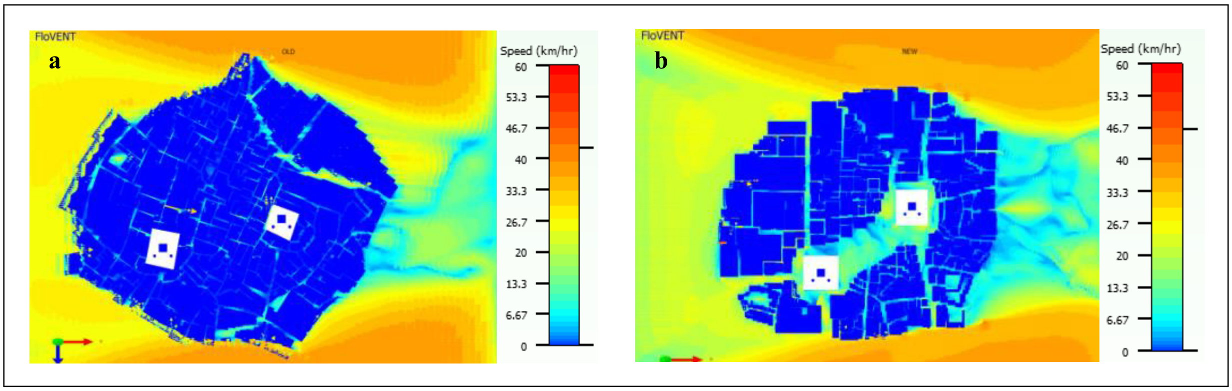

Fig 5: a (urban structure before changes) and b (urban structure after changes) are shown the air speed in the two models

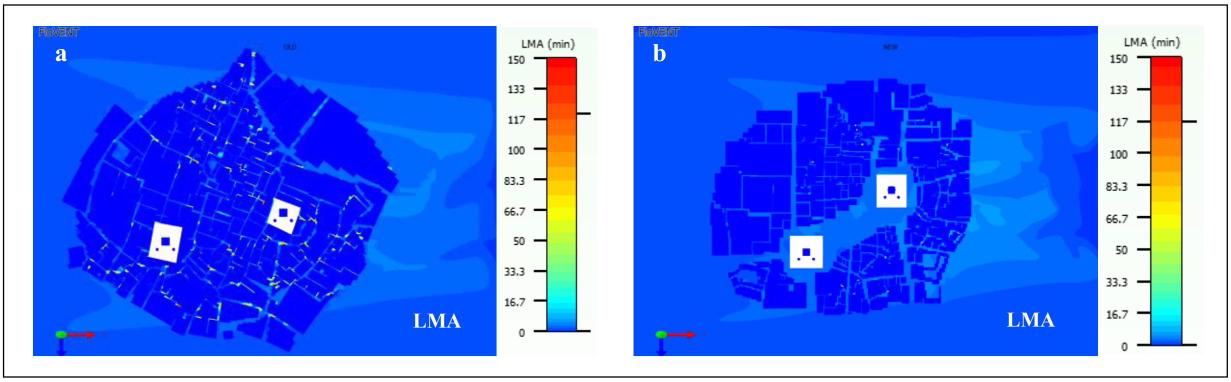

Figure 6: a (the urban structure before changes) and b (the urban structure after change) are shown the local mean age of the air (LMA)

6. Conclusion

A comparison between the old urban structures of historic Karbala in the early period of the last century (1920) with its developed urban structures in the 1990s reveals that the dynamic airflow circulation in the new urban structures is much faster move than in old ones. The FloVENT analysis has shown through two key simulation measures: the speed of airflow smoothly continues through urban corridors in the central zone; and a duration that needs for changing air. In this study, the effect of such changes on the airflow circulation and speed was approached using simulation package. The results show that a great effect can be observed on the mechanism of airflow speed as the masses-voids distribution is affected after many additions and removes applied on the physical-structural forms and street networks.

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